# Voltage Supply for dodecapole lens in PEEM3

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Due to the mechanical misalignments, ellipticity of focusing fields and contamination, considerable deterioration of the image quality can be caused in high resolution electron microscope. Multipole lens are commonly used as focusing, deflecting and image correcting elements in electron optics. In PEEM3, electrostatic and magnetic dodecapole lens are used. By proper powering the dodecapole lens, dipole and quadrupole field in an arbitrary direction can be achieved, it can also act as hexapole and octupole lens. Furthermore, with adding equal potential to the twelve electrodes, the dodecapole can also act as einzel lens. The proper voltage supple for electrostatic dodecapole will be discussed in this note, but the method can be also applied to magnetic power supply.

The dodecapole used in PEEM3 consists of twelve rods positions as a regular dodecagon around a circle as shown in figure 1.

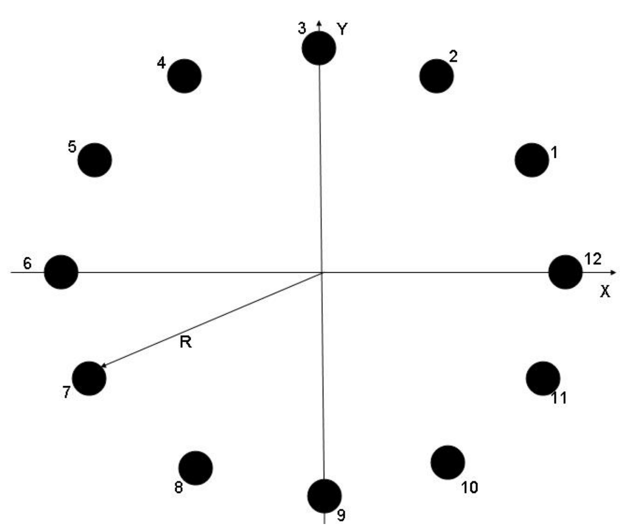


Fig.1 Electrode configuration of dodecapole in PEEM3. Numbers are the order of electrodes.

Within the inner region (<R) both the electric and magnetic field can be derived from potential by solving Laplace's equation because the inner region contains neither electric charges nor currents. It is convenient to expand the potential in a series of plane multipoles as following

$$\varphi(r,\theta) = \mathrm{Re}\sum_{n=0}^{\infty} V_n(r,\theta) r^n e^{-in\theta} \qquad (1)$$

where radius r and angle θ are the polar coordinates. $V_n(r,\theta)$ represent the complex strength (deflection, focusing, etc.) of the n-fold multipole components and are integrals along Z for paraxial ray propagation. Thus, what you want to be able to control are these integrals. In PEEM3 dodecapole case (fig.1), twelve electrodes are equally spaced around the inside of cylinder. The voltage at each point along a circle of radius R extending from z=-L to z=+L can be controlled by power supply. Thus at r=R, we have

$$\begin{aligned} V(R, z, \theta) &= V_{electrode}(\theta) \qquad && |z| \le L \qquad (2) \\ &= 0 && |z| > L. \end{aligned}$$

Now, if the voltage supply of electrode have the form of $V_{electrode}(\theta) = \mathrm{Re}\, e^{im\theta+\delta}$ where δ is a phase shift. Plugging that in and using the orthogonality of $e^{im\theta}$ we see that

$$\begin{aligned} V_n(R,Z) &= \frac{1}{R^m} e^{i\delta} \qquad && n = m \qquad (3) \\ &= 0 && n \neq m \end{aligned}$$

Thus, we see that by putting in a trig-function pattern of voltages cos(θ*n+δ) on a sufficient number of electrodes, we can control any specific multipole element we want. The next step in realism is to replace this infinite set of electrodes with a finite number. If you have a set of electrodes centered at angles $\theta_j = 2*\pi*j/M$, j=1,2,3,…,M, the voltage supply distribution for the electrodes can be described by a superposition of multipole fields as following

$$V_i = a*\cos(\theta_j*n) + b*\sin(\theta_j n) \qquad (4)$$

For dodecapole case, twelve electrodes give twelve degrees of freedom, then twelve linearly independent voltage supplies can be used. For dipole fields, the ratios of the dodecapole electrodes ( electrode orders are shown in fig.1) are as following

$$\begin{aligned}
&V_1 = \frac{\sqrt{3}}{2}V_x + \frac{1}{2}V_y, && V_2 = \frac{1}{2}V_x + \frac{\sqrt{3}}{2}V_y \\
&V_3 = V_y, && V_4 = -\frac{1}{2}V_x + \frac{\sqrt{3}}{2}V_y \\
&V_5 = -\frac{\sqrt{3}}{2}V_x + \frac{1}{2}V_y, && V_6 = -V_x \\
&V_7 = -\frac{\sqrt{3}}{2}V_x - \frac{1}{2}V_y, && V_8 = -\frac{1}{2}V_x - \frac{\sqrt{3}}{2}V_y \\
&V_9 = -V_y, && V_{10} = \frac{1}{2}V_x - \frac{\sqrt{3}}{2}V_y \\
&V_{11} = \frac{\sqrt{3}}{2}V_x - \frac{1}{2}V_y && V_{12} = V_x
\end{aligned} \qquad (5)$$

For quadrupole fields, the ratios of the dodecapole electrodes ( electrode orders are shown in fig.1) are as following

$$\begin{aligned}
&V_1 = \frac{1}{2}V_x + \frac{\sqrt{3}}{2}V_y, && V_2 = -\frac{1}{2}V_x + \frac{\sqrt{3}}{2}V_y \\
&V_3 = -V_x, && V_4 = -\frac{1}{2}V_x - \frac{\sqrt{3}}{2}V_y \\
&V_5 = \frac{1}{2}V_x - \frac{\sqrt{3}}{2}V_y, && V_6 = V_x \\
&V_7 = \frac{1}{2}V_x + \frac{\sqrt{3}}{2}V_y, && V_8 = -\frac{1}{2}V_x + \frac{\sqrt{3}}{2}V_y \\
&V_9 = -V_x, && V_{10} = -\frac{1}{2}V_x - \frac{\sqrt{3}}{2}V_y \\
&V_{11} = \frac{1}{2}V_x - \frac{\sqrt{3}}{2}V_y && V_{12} = V_x
\end{aligned} \qquad (6)$$

For hexapole fields, the ratios of the dodecapole electrodes ( electrode orders are shown in fig.1) are as following

$$\begin{aligned} &V_1 = V_y\,, && V_2 = -V_x \\ &V_3 = -V_y\,, && V_4 = V_x \\ &V_5 = V_y\,, && V_6 = -V_x \\ &V_7 = -V_y\,, && V_8 = V_x \\ &V_9 = V_y\,, && V_{10} = -V_x \\ &V_{11} = -V_y && V_{12} = V_x \end{aligned} \qquad (7)$$

In PEEM2 hexapole deflector which was designed by Gary G. Hembree, only dipole field voltage supply is wired for deflection. The electrode configuration of this hexapole is shown in figure 2.

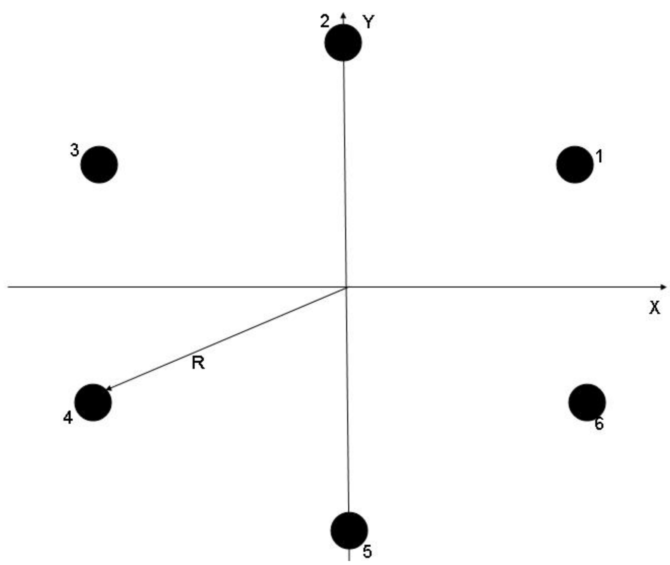


Fig.2 Electrode configuration of hexapole in PEEM2. Number is the order of electrodes.

Based on Eq.(4), the voltage supply distribution can be derived as following

$$\begin{aligned} &V_1 = \frac{\sqrt{3}}{2}V_x + \frac{1}{2}V_y\,, && V_2 = V_y \\ &V_3 = -\frac{\sqrt{3}}{2}V_x + \frac{1}{2}V_y\,, && V_4 = -\frac{\sqrt{3}}{2}V_x - \frac{1}{2}V_y \\ &V_5 = -V_y\,, && V_6 = \frac{\sqrt{3}}{2}V_x - \frac{1}{2}V_y \end{aligned} \qquad (8)$$

Eq.(8) equation which we derived is exact same as the voltage supply distribution by Gary G. Hembree. The maximum outputs he used are +/- 200v, plug in equation $\frac{\sqrt{3}}{2}V_x + \frac{1}{2}V_y$=200 and Vx=Vy, the maximum magnitude for either Vx or Vy is 146.4 volts. The voltage supply resistors network can be refereed in his design note [1].

Reference:

[1] Gary G. Hembree, Electronic design of voltage sources for hexapole deflector and an octupole stigmator in a photoelectric microscope, 1997, Arizona state University